Submitted: 15 March, 2023 Accepted: 12 May, 2023 Published: 03 November, 2023 DOI:10.22514/jocpd.2023.088

ORIGINAL RESEARCH

Journal of Clinical Pediatric Dentistry

Relationship between time to hemostasis and outcomes of pulpotomy using iRoot BP Plus in symptomatic young permanent teeth: a prospective study

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Abstract

The aim was to investigate the relationship between time to hemostasis and pulpotomy outcomes with the use of iRoot BP Plus (Innovative Bioceramics, Vancouver, Canada) for young permanent teeth of patients aged from 7 to 12 with symptomatic irreversible pulpitis and evaluate the outcomes of pulpotomy. The present study was a prospective cohort study. Two hundred and six young permanent teeth with symptomatic irreversible pulpitis underwent pulpotomy with the use of iRoot BP Plus. All patients underwent pulpotomy in accordance with a standardized protocol. Patients were postoperatively re-called after 3, 6, 12 months. Successful cases were defined according to clinical and radiographic evaluations. Main outcome measures included tooth position, cave shape, previous restoration, preoperative symptoms, time to hemostasis and outcomes. On the basis of univariate linear regression model, the relationships between time to hemostasis was evaluated, and $p < 0.05$ indicated a difference that achieved statistical significance. One hundred and ninety-three teeth can be evaluated after a follow-up for 6 to 36 months. The mean age of subjects was 9.43 $\pm$ 1.51 years. The overall clinical and radiographic success rate of pulpotomy reached 71.5% (138/193). After adjusting potential confounders (age, sex, previous restoration), non-linear relationship was detected between time to hemostasis and pulpotomy outcomes whose point was 4 minutes. The relationship between time to hemostasis and pulpotomy outcomes is non-linear. Pulpotomy outcomes was negatively related with time to hemostasis when time to hemostasis is more than 4 minutes.

Keywords

Pulpotomy; Young permanent teeth; Hemostasis; Relationship

1. Introduction

Caries exposure of young permanent teeth can result in irreversible pulpitis of the pulp tissue and halt the development of roots [1]. In such cases, root canal therapy (RCT) is often performed to remove all of the pulp tissue [2]. However, complete removal of vital pulp can impede root growth and increase the likelihood of tooth fractures [3]. To address this issue, pulpotomy has emerged as a promising method for retaining more hard and soft tissue while preserving vital pulp to some extent. By leaving behind some vital pulp tissue, pulpotomy can promote the growth of young permanent teeth with incomplete apical foramen [4]. This residual vital pulp can also help protect the tooth from root fractures. Therefore, when performing endodontic treatment on immature permanent teeth, it is essential to retain vital pulp tissue to the greatest extent possible.

The ideal pulp-capping agents are required to exhibit several desirable properties, such as anti-inflammatory and antibacterial properties, non-toxicity and favorable sealing capabilities, while also being able to induce dentin mineralization [5]. Recently, a novel bioceramic material called iRoot BP Plus (Innovative Bioceramics, Vancouver, Canada) has shown promising results for pulp capping, with outcomes consistent with those of Mineral Trioxide Aggregate (MTA) in dog teeth pulpotomy studies [6]. In addition to its comparable clinical efficacy, iRoot BP Plus has also been found to have high biocompatibility, as demonstrated by existing research [7]. As a result, it has been proposed as an alternative to calcium hydroxide for pulp capping in pulpotomy procedures [8]. Overall, iRoot BP Plus shows great potential for use as a pulp-capping agent in clinical practice.

While pulpotomy is a beneficial procedure for young permanent teeth with symptomatic irreversible pulpitis, there are some limitations that need to be considered [2]. Despite the potential benefits of pulpotomy, factors that can affect its outcome are still unknown. Identifying factors that predict pulpotomy outcomes early on would enable clinicians to make adaptive changes to the treatment plan to improve outcomes. Time to hemostasis is a clinical parameter that can

be easily evaluated and can help clinicians assess the state of the pulp [9]. However, there is currently no agreement on the relationship between time to hemostasis and pulpotomy outcomes. Witherspoon *et al*. [10] suggested that a hemostatic period of 10 minutes, achieved through irrigation with 1% Sodium Hypochlorite (NaOCl), results in a remaining pulp in a reversible inflammatory state. Additionally, Taha *et al*. [11] reported a 100% success rate in stopping blood flow in 6 minutes before vital pulp therapy by directly contacting the exposed pulp with a cotton pellet moistened with 1% NaOCl. Moreover, Qudeimat *et al*. [12] found that vital pulp therapy with a hemostatic period of up to even 24 minutes can effectively treat teeth with irreversible pulpitis. Having concrete evidence of the prognostic impact of time to hemostasis could aid dentists in their choice of endodontic treatment and improve outcomes for affected teeth.

The aim of present study was to investigate the relationship between time to hemostasis and pulpotomy outcomes with the use of iRoot BP Plus (Innovative Bioceramics, Vancouver, Canada) for young permanent teeth of patients aged from 7 to 12 with symptomatic irreversible pulpitis and evaluate the outcomes of pulpotomy.

2. Materials and method

2.1 Study design and population

To guarantee that the results were properly reported, we adopted the guidelines of the for Strengthening the Reporting of Observational research in Epidemiology. We enrolled patients aged from 7 to 12 years, attending Department of Stomatology, Yuecheng People's Hospital, Zhejiang Province, China. The period of recruitment was from June 2020 to June 2022.

Study flow diagram was presented in **Supplementary Fig. 1**. The study followed the American Association of Endodontists (AAE) guidelines [13] to establish standards for patient inclusion and exclusion. Patients were required to have immature permanent molars and premolars with deep caries affecting at least two-thirds of the dentine and a clinical diagnosis of symptomatic irreversible pulpitis with normal apical tissue. A comprehensive assessment was performed, which included a patient history, clinical and radiographic examination, and pulp sensibility testing with cold and electric pulp testing. Diagnostic terminology approved by the AAE guidelines was used to determine pulpal and periapical diagnosis. Patients were diagnosed with symptomatic irreversible pulpitis based on a history of spontaneous pain or lingering pain that could be reproduced by cold testing using Endofrost (Coltene/Whaledent Dental Meterial & Equipment Trading, Beijing, China). Patients with immature roots, a healthy periodontium (probing pocket depth $\leq$3 mm and normal mobility), and no response to palpation and percussion testing were included. Teeth that did not respond to vitality testing, had a sinus, swelling, non-restorable crown, mature roots or showed no pulp exposure after caries excavation were excluded. Patients were also excluded if they had insufficient bleeding after pulp exposure suggestive of partial necrosis of pulp, inability to control bleeding within 20 minutes, a history of recent analgesic or antibiotic use, as defined by use within the previous week or previous month, respectively. Eligible patients and their caregivers were informed of the procedure, associated risks, benefits and alternative treatment options and the caregivers were required to provide written informed consent before participation in the study.

The sample size was calculated using G*Power software (version 3.1.9.2, the Department of Experimental Psychology at Heinrich-Heine-University Düsseldorf, Düsseldorf, North Rhine-Westphalia, Germany) based on a power analysis. With an effect size of 0.3, α of 0.05 and 1-β of 0.9, a sample size of 183 was calculated to achieve an actual power of 0.90.

2.2 Treatment and outcomes

The periapical radiograph was taken using a Sirona periapical film machine (Sirona Xios XG Supreme periapical X-ray system, Sirona, York, Pennsylvania, United States) after completion of the clinical examination to establish the preoperative diagnosis. The verbal numerical rating scale (vNRS) was used to measure the intensity of pain postoperatively, as it has been shown to be a reliable method for children aged 6 years and older [14].

All procedures were performed by the same pediatric dentist following completion of clinical and radiographic assessments, under the supervision of an experienced instructor, according to the established protocol. First, 4% articaine with 1:100,000 epinephrine (X19990003, ACTEON, Merignac, France) was administered to anesthetize the tooth, followed by isolation using a dental dam (Kerr, Germany). Caries removal was performed with a sterile, high-speed diamond under water cooling, and the tooth surface was disinfected with 5% sodium hypochlorite (NaOCl), followed by a rinse with 2.5% NaOCl. The coronal pulp was then superficially excavated to a depth of 2–3 mm with a sterile, high-speed diamond bur and the pulp status and bleeding were evaluated. Hemostasis was achieved by placing a slightly saline-wetted cotton pellet gently over the amputated pulps and was evaluated every minute [15]. If hemostasis was achieved, the time was recorded and pulp capping was performed. If hemostasis was not achieved within 20 minutes, the tooth was excluded from the study and underwent revascularization, depending on the remaining pulp state. Next, iRoot BP Plus was applied and gently adapted to a thickness of 2–3 mm on pulp using moist cotton pellets. A protective base of resin-modified glass ionomer (Vitrebond, 3M, ESPE, St Paul, MN, USA) was applied over the iRoot BP Plus layer, followed by a cotton pellet. Finally, a stainless steel crown or resin composite was used for tooth restoration, depending on the amount of remaining tooth structure after 2 weeks of observation.

The patient is required to receive clinical and radiographic examinations at 3, 6 and 12 months after the operation. Successful cases should meet the following criteria, as determined by three observers: (1) no history of spontaneous discomfort or pain; (2) no tenderness to cold or heat stimuli, palpation or percussion; (3) no abnormal mobility; (4) normal soft tissue surrounding the tooth, without swelling or sinus tracts; (5) intact filling materials and normal function; (6) no radiographic evidence of external resorption or periradicular tissue

pathology; (7) no radiographic evidence of internal resorption or intraradicular pathology; (8) continued radiographic evidence of root growth in immature roots. The Cohen Kappa statistics indicated good interobserver agreement among the three observers, with scores ranging from 0.70 to 0.85.

2.3 Statistical analysis

Continuous variables were presented as mean ± standard deviation, while categorical variables were presented as percentages. Statistical differences between means and proportions of groups were determined using one-way Analysis of Variance (ANOVA) and chi-square tests, respectively. Logistic regression analysis was used to perform univariate analysis. The results of both non-adjusted and multivariate adjusted models were reported, in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement recommendation. To identify any non-linear relationships between time to hemostasis and pulpotomy outcomes, a generalized additive model (GAM) was used. If a non-linear correlation was observed, a two-piecewise linear regression model was used to calculate the threshold effect of time to hemostasis on pulpotomy outcomes, based on the smoothing plot. The inflection point, where the maximum model likelihood was used, was calculated using a recursive method if the ratio between time to hemostasis and pulpotomy outcomes was apparent in the smoothed curve [9]. Subgroup analyses were conducted using stratified linear regression models, and the likelihood ratio test was used to inspect for interactions and modifications of the subgroup. All analyses were performed using the R statistical software package (version 4.1.0, http://www.R-project.org, The R Foundation, Vienna, Australia), and a p-value of < 0.05 indicated statistical significance.

3. Results

3.1 The selection of participants and baseline characteristics of participants

A total of 232 patients were enrolled in the study. Of these, the allocated procedure could not be completed in 16 patients since pulpal bleeding could not be controlled within 20 minutes. Thus, 206 immature permanent teeth with symptomatic irreversible pulpitis underwent pulpotomy using iRoot BP Plus. Of the 206 permanent teeth initially included, 13 participants were lost to follow-up. Thus, the outcomes of 193 permanent teeth from 91 males and 102 females were evaluated, resulting in a follow-up rate of 93.7%.

Baseline characteristics were listed in Table 1. The mean age of patients undergoing pulpotomy was 9.43 ± 1.51 years. The following test period fell into a range of 6–35 months, with a mean of 13.18 ± 5.86 months. During the follow-up, pulpotomy achieved a success rate of 71.5% (138/193).

Compared with success group of pulpotomy outcomes, patients had a significantly higher portion to have previous restoration, a significantly lower portion to have spontaneous pain, and significantly more time to hemostasis.

3.2 Univariate analysis

The results of univariate analysis were presented in Table 2. The results of univariate analysis showed that previous restoration and more time to hemostasis were correlated with lower successful rate of pulpotomy. We also found that sex, age, maxilla or mandible, cave shape, referred pain, cold test, pain level of cold test, heat test, pain level of heat test, electrical vitality test, percussion sensitivity was not associated with pulpotomy outcomes.

3.3 The results of relationship between time to hemostasis and pulpotomy outcomes

Univariate linear regression model was employed to evaluate the relationships between time to hemostasis and pulpotomy outcomes. Moreover, we established the non-adjusted and adjusted models in Table 3. In crude model, time to hemostasis showed positive correlation with failure rate of pulpotomy (Odds Ratio (OR) = 1.08, 95% Confidence Interval (CI): 1.02 to 1.13, p = 0.006). In minimally adjusted model (adjusted age, sex) and fully adjusted model, the result did not have obvious changes (OR = 1.11, 95% CI: 1.04 to 1.18, p = 0.001 in minimally adjusted model; OR = 1.10, 95% CI: 1.03 to 1.18, p = 0.004).

3.4 The analyses of non-linear relationship

As time to hemostasis was continuous variable, the analyses of non-linear relationship are necessary. In the present study (Fig. 1), we found that the relationship between time to hemostasis and pulpotomy outcome was non-linear (after adjusting sex, age, maxilla or mandible, previous restoration, cave shape, referred pain, cold test, pain level of cold test, heat test, pain level of heat test, electrical vitality test, percussion sensitivity).

By two-piecewise linear regression model, we calculated the inflection point was 4. When time to hemostasis was more than 4 minutes, OR, 95% CI and p value were 1.12, 1.04 to 1.22 and 0.005, respectively. However, we observed no relationship between time to hemostasis and pulpotomy outcomes on the left of inflection point (0.99, 0.63 to 1.54, 0.958) (Table 4).

4. Discussion

Recent advancements in biological materials have opened up new possibilities for treatment that were once considered impossible. However, pulpotomy, despite being a viable treatment option for damaged pulp and immature permanent teeth, still poses significant challenges due to the intricate root canal system and complications associated with the treatment process. Accurately judging the state of dental pulp is crucial in such cases, but in clinical settings, it is often done through visual observation, without any standard for determining the amount of dental pulp that can be retained [16]. Incorrect evaluation of the pulp state can lead to confusion in subsequent treatment and clinical challenges, resulting in an inadequate amount of pulp removal, which could affect the clinical prognosis [17]. Inappropriate amounts of pulp removal can lead to incomplete control of inflammation or potential trauma to

TABLE 1. Baseline characteristics of participants.

Outcome	Success	Failure	*p*-value
Total (n (%))	138 (71.5)	55 (28.5)	
Age (years, mean ± sd)	9.47 ± 1.40	9.56 ± 1.53	0.216
Sex (n (%))			
Male	70 (50.7)	21 (38.2)	0.115
Female	68 (49.3)	34 (61.8)	
Maxilla or mandible (n (%))			
Maxilla	46 (33.3)	22 (40.0)	0.381
Mandible	92 (66.7)	33 (60.0)	
Tooth position (n (%))			
Premolar	21 (15.2)	10 (18.2)	0.613
Molar	117 (84.8)	45 (81.8)	
Previous restoration (n (%))			
Yes	57 (41.3)	32 (58.2)	0.034*
No	81 (58.7)	23 (41.8)	
Cave shape (n (%))			
Occlusal Surface Only	21 (15.2)	10 (18.2)	0.613
Proximal Surface Involved	117 (84.8)	45 (81.8)	
Spontaneous pain (n (%))			
Yes	130 (94.2)	47 (85.5)	0.047*
No	8 (5.8)	8 (14.5)	
Reffered pain (n (%))			
Yes	21 (15.2)	9 (16.4)	0.843
No	117 (84.8)	46 (83.6)	
Cold test (n (%))			
Tenderness without delaying pain	11 (8.0)	5 (9.1)	
Tenderness with delaying pain <30 s	106 (76.8)	44 (80.0)	0.729
Tenderness with delaying pain ≥30 s	21 (15.2)	6 (10.9)	
Pain level of cold test (n (%))			
<5	98 (71.0)	36 (65.5)	0.449
≥5	40 (29.0)	19 (34.5)	
Heat test (n (%))			
Normal	40 (29.0)	19 (34.5)	
Tenderness without delaying pain	45 (32.6)	15 (27.3)	0.149
Tenderness with delaying pain <30 s	43 (31.2)	21 (38.2)	
Tenderness with delaying pain ≥30 s	10 (7.2)	0 (0.0)	
Pain level of heat test (n (%))			
<5	124 (89.9)	52 (94.5)	0.299
≥5	14 (10.1)	3 (5.5)	
Electrical vitality test difference (n (%))			
<10	104 (75.4)	40 (72.7)	0.704
≥10	34 (24.6)	15 (27.3)	
Percussion sensitivity (n (%))			
(−)	100 (72.5)	45 (81.8)	
(±)	20 (14.5)	5 (9.1)	0.395
(+)	18 (13.0)	5 (9.1)	
Time to hemostasis (min, mean ± sd)	7.39 ± 5.06	10.25 ± 5.63	<0.001*

*sd: Standard Deviation. Statistical differences between means and proportions of groups were determined using one-way ANOVA and chi-square tests, respectively. *p-value < 0.05.*

TABLE 2. The results of univariate analysis for pulpotomy outcomes.

Covariate	Statistics	OR (95% CI)	*p*-value
Sex			
Male	91 (47.15%)	ref	0.066*
Female	102 (52.85%)	1.67 (0.97, 2.90)	
Age, yr	10.34 ± 2.72	0.97 (0.93, 1.02)	0.229
Maxilla or mandible (%)			
Maxilla	68 (35.23%)	ref	0.233
Mandible	125 (64.77%)	0.72 (0.42, 1.24)	
Tooth position (%)			
Premolar	31 (16.06%)	ref	0.600
Molar	162 (83.94%)	0.83 (0.42, 1.66)	
Previous restoration (%)			
Yes	89 (46.11%)	ref	0.010*
No	104 (53.89%)	0.49 (0.28, 0.84)	
Cave shape (%)			
Occlusal Surface Only	31 (16.06%)	ref	0.684
Proximal Surface Involved	162 (83.94%)	0.87 (0.43, 1.73)	
Spontaneous pain (%)			
Yes	177 (91.71%)	ref	0.465
No	16 (8.29%)	1.33 (0.62, 2.82)	
Reffered pain (%)			
Yes	30 (15.54%)	ref	0.679
No	163 (84.46%)	0.86 (0.42, 1.76)	
Cold test (%)			
Tenderness without delaying pain	16 (8.29%)	ref	
Tenderness with delaying pain <30 s	150 (77.72%)	1.05 (0.41, 2.66)	0.921
Tenderness with delaying pain ≥30 s	27 (13.99%)	0.78 (0.24, 2.58)	0.689
Pain level of cold test (%)			
<5	134 (69.43%)	ref	0.087*
≥5	59 (30.57%)	1.65 (0.93, 2.92)	
Heat test (%)			
Normal	59 (30.57%)	ref	
Tenderness without delaying pain	60 (31.09%)	0.73 (0.37, 1.45)	0.373
Tenderness with delaying pain <30 s	64 (33.16%)	0.94 (0.51, 1.76)	0.856
Tenderness with delaying pain ≥30 s	10 (5.18%)	0.00 (0.00, Inf)	0.996
Pain level of heat test (%)			
<5	176 (91.19%)	ref	0.212
≥5	17 (8.81%)	0.48 (0.15, 1.53)	
Electrical vitality test difference (%)			
<10	144 (74.61%)	ref	0.664
≥10	49 (25.39%)	1.14 (0.63, 2.07)	
Percussion sensitivity (%)			
(−)	145 (75.13%)	ref	
(±)	25 (12.95%)	0.83 (0.33, 2.11)	0.701
(+)	23 (11.92%)	0.61 (0.24, 1.54)	0.294
Time to hemostasis, min	8.21 ± 5.37	1.08 (1.02, 1.13)	0.006*

OR: Odds Ratio; CI: Confidence Interval; Ref: reference; Logistic regression analysis were used to perform univariate analysis.
**p-value < 0.05.*

TABLE 3. Relationship between time to hemostasis and pulpotomy outcomes in different models.

Outcome	Crude model		Minimally adjusted model		Fully adjusted model	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Time to hemostasis, min	1.08 (1.02, 1.13)	0.0055*	1.11 (1.04, 1.18)	0.001*	1.10 (1.03, 1.18)	0.004*

*OR: Odds Ratio; CI: Confidence Interval; Crude model: we did not adjust other covariants; Minimally adjusted model: we adjusted age and sex; Fully adjusted model: we adjusted sex, age, maxilla or mandible, previous restoration, cave shape, reffered pain, cold test, pain level of cold test, heat test, pain level of heat test, electrical vitality test, percussion sensitivity. Logistic regression analysis was used in non-adjusted and multivariate adjusted models. *p-value < 0.05.*

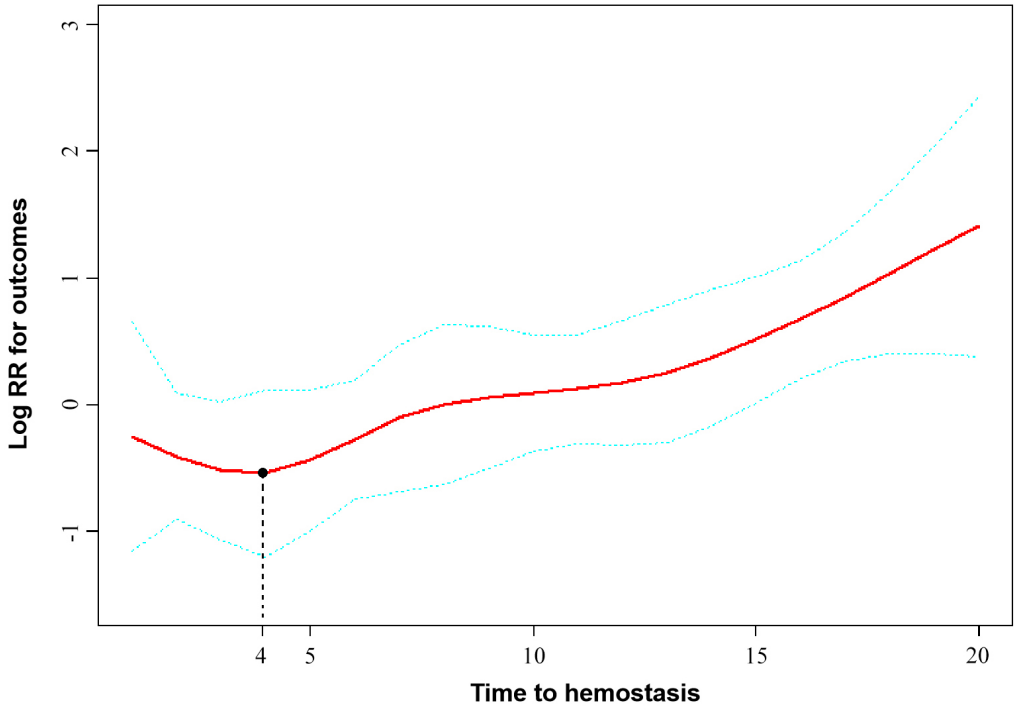

FIGURE 1. relationship between time to hemostasis and pulpotomy outcomes. A threshold, nonlinear relationship between time to hemostasis and pulpotomy outcomes was found in a generalized additive model (GAM) after adjusting sex, age, maxilla or mandible, previous restoration, cave shape, referred pain, cold test, pain level of cold test, heat test, pain level of heat test, electrical vitality test, percussion sensitivity. Blue bands represent the 95% CI form the fit.

TABLE 4. The results of two-piecewise linear regression model between time to hemostasis and pulpotomy outcomes.

Inflection point of time to hemostasis (min)	OR	95% CI	*p*-value
<4	0.99	(0.63, 1.54)	0.958
≥4	1.12	(1.04, 1.22)	0.005*

*OR: Odds Ratio; CI: Confidence Interval; Two-piecewise linear regression model was used. The inflection point, where the maximum model likelihood was used, was calculated using a recursive method. Effect: pulpotomy outcomes; Cause: time to hemostasis; Adjusted: sex, age, maxilla or mandible, previous restoration, cave shape, reffered pain, cold test, pain level of cold test, heat test, pain level of heat test, electrical vitality test, percussion sensitivity. *p-value < 0.05.*

the child. A successful [18] involves the surgical removal of inflamed pulp and covering the remaining root pulp, which has a continuous blood supply, with a biocompatible material to protect it from further damage and promote healing, creating a coronal seal. While pulpotomy is rarely performed on immature permanent teeth with exposed caries due to its uncertain prognosis, it is more commonly used for immature permanent incisors that are exposed due to trauma rather than caries [19]. It is essential to identify the factors that can assist in accurately predicting the prognosis of pulpotomy preoperatively or intraoperatively.

The importance of preoperative evaluation is critical as there is no standard guideline for the indications of pulpotomy in immature permanent teeth. Diagnosis of irreversible pulpitis is determined by the patient's clinical symptoms and reactions to temperature tests. Irreversible pulpitis is typically characterized by referred or spontaneous pain, which indicate the pulp status [20]. Cold testing has been noted as the most effective

in detecting necrotic pulp, and therefore remains necessary before treating teeth with pulp-exposed lesions or deep caries [21]. However, the present study found that referred pain, spontaneous pain and thermal testing were not significantly correlated with pulpotomy prognosis, consistent with the findings of Liu *et al*. [22] and Kundzina *et al*. [23]. Additionally, pulp electrical vitality testing and percussion results were also not significantly correlated with pulpotomy prognosis in the present study. Similar to the present study, previous research has suggested that pulp electrical vitality test data cannot accurately indicate the pulp status, but rather indicates if Aδ fibers are functioning normally [24, 25]. Besides, the percussion of irreversible pulpitis teeth did not remarkably affect their crown pulp prognosis [26], such that positive percussion patients were still covered. Unintervened pulp exposure attributed to caries would eventually lead to progressive spread of pulp inflammation, whereas the test result of pulp sensibility may not indicate this progression [24]. Nevertheless, since this study had limited cases, it is imperative to explain exactly how preoperative symptoms and physical examination affect pulpotomy prognosis.

In terms of pulpotomy prognosis, the selection of pulp capping material is crucial. While MTA has been widely used in pulpotomy, it has limitations when used for pulp capping, MTA needs to be regulated with normal saline before application, making clinical operation steps more tedious. In addition, MTA containing Bismuth(III) oxide ($Bi_2O_{3)}$ can be toxic to dental pulp cells and cause teeth discoloration [27]. On the other hand, iRoot BP Plus is a novel premixed material with excellent physicochemical properties and biocompatibility [28] and it can induce mineralization and odontoblastic differentiation-associated gene expression. The effectiveness of iRoot BP Plus as a pulp capping agent for treating mature permanent teeth with pulp exposure caused by caries has been studied, and the success rate at 1, 2 and 3 or more years after surgery was 98%, 89% and 81%, respectively [22]. Pulpotomy with iRoot BP Plus as a pulp capping agent achieved a high success rate, indicating that iRoot BP Plus can treat immature permanent teeth with dental caries exposure in vital pulp therapy (VPT).

Evaluation of pulp state in the process of pulpotomy is a vital factor for the prognosis. No agreement has been reached on the haemostasis approach and detailed period though hemostatic period has been employed for pulp state evaluation. Witherspoon *et al*. [10] have suggested that when hemostatic period was regulated in 10 min through irrigation with 1% NaOCl, the remaining pulp achieved the reversible inflammatory state. Moreover, Taha *et al*. [25] directly contacted the exposed pulp with a cotton pellet moistened with 1% NaOCl for stopping the flow of blood before VPT and had a high rate of success (100%). As revealed by the results of Qudeimat *et al*. [12], the VPT treatment has a hemostatic period of even 24 min, and it can well treat teeth with irreversible pulpitis. To our best knowledge, for the first time, non-linear relationship was detected between time to hemostasis and pulpotomy outcomes whose point was 4 minutes. In present study, pulpotomy outcomes was negatively related with time to hemostasis when time to hemostasis is more than 4 minutes. Thus, we suggest that immature permanent teeth exposed to caries could be treated by pulpotomy if hemostasis could be achieved in 4 minutes in clinical situation. However, if time to hemostasis is more than 4 minutes, treatment failure frequency was increased (OR = 1.12, p-value = 0.0047).

Our study had several limitations. First, we were unable to launch a comprehensive central trial to recruit participants. However, all participants were diagnosed and treated by the same expert pediatric dentist according to AAE guideline. Thus, this limitation may not have distorted the findings. A comprehensive central trial should be launched in the future to add evidence. Second, the limitation of our study might lay in the possibility of hidden bias due to lack of randomization. Finally, the total number of trial participants was relatively small and all participants were Asians. Thus, the generalizability of this cohort study related to race may be limited, and therefore should be interpreted with caution.

On the basis of our study, the totality of data indicated that pulpotomy for pulp which can achieve hemostasis less than 4 minutes might offer improved efficacy and safety compared with those cannot achieve hemostasis in 4 minutes. Our findings provide additional evidence to help to support decision making when choosing a first-line treatment with patients with pulpitis.

5. Conclusions

The relationship between time to hemostasis and pulpotomy outcomes is non-linear. Pulpotomy outcomes was negatively related with time to hemostasis when time to hemostasis is more than 4 minutes.

AVAILABILITY OF DATA AND MATERIALS

The datasets generated and/or analyzed during the current study are not publicly available due individual privacy can be compromised but are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

MS, WL—designed the research study. MS, DZ—performed the research. MS, DZ and JY—analyzed the data. MS and DZ—wrote the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The protocol of this study gained approval from the local Ethics Committee (Shaoxing Yuecheng People's Hospital, No. (MR-33-22-020114)) and registered in the Chinese Trials Registry (ChiCTR2100044580). All patients' parent or guardian provided informed consent.

ACKNOWLEDGMENT

Our gratitude to the dentists, dental assistants and patients who participated in the study.

FUNDING

The study was funded by Shaoxing Basic Public Welfare Project (2022A14035).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jocpd.com/files/article/1720327004322971648/attachment/Supplementary%20material.docx.

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How to cite this article: Min Sheng, Denghui Zhang, Jing Yan, Weiqin Li. Relationship between time to hemostasis and outcomes of pulpotomy using iRoot BP plus in symptomatic young permanent teeth: a prospective study. Journal of Clinical Pediatric Dentistry. 2023; 47(6): 142-149. doi: 10.22514/jocpd.2023.088.